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SIMULATED THERMAL EFFLUENT

into

LAKE ONTARIO

APRIL, 1968

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SIMULATED THERMAL EFFLUENT
INTO LAKE ONTARIO

APRIL, 1968

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ABSTRACT

The dispersion pattern of Duffin Creek water into Lake Ontario was determined under two different wind conditions in the spring time when the flow was 180 cfs and 5°F warmer than the lake water. Continuous dye injection was used to trace the plume. Based upon experimental results, a model was developed which predicts maximum concentrations within 25 percent for distances up to 4000 feet from source. Maximum dye concentrations varied as the (distance)^{-0.8}. The model applied to an existing thermal generating station at Lakeview was capable of predicting maximum temperatures within 25 percent of measured values.

SIMULATED THERMAL EFFLUENT

INTO LAKE ONTARIO

INTRODUCTION

There is relatively little information available that allows one to predict what effect an effluent released at the shore will have on adjacent areas. Obviously, this type of information is mandatory for the proper locating of municipal service intakes and outlets as well as the effect of industry on adjacent areas. The information must be formulated in such a way that it can be used for different loading and longshore current conditions. The Duffin Creek study was designed with the equations formulated having three variables; loadings, longshore currents and distance from the source. In addition, the equations incorporate a temperature difference between the effluent and the receiving body which is likely to be the case for most discharge conditions. The equations were developed from controlled experiments in the field, then checked by applying them to a completely different area. They were also compared to results from similar studies on Lake Huron as a test of their general application. While the equations developed are obviously not universal or capable of handling all physical situations, they do provide a valuable prediction vehicle for small discharges at the shore. As more field studies are conducted, it will be possible to expand the equations to incorporate more physical factors and produce more accurate predictions.

An interim approach to the problem would be to check the application of the prediction equations with limited field surveys, then decide whether it is necessary to conduct full studies or accept the existing equations. In each case, the results should be such that they can be extended and maximized by utilizing longterm meteorological data.

OUTLINE OF PROBLEM

At present, a thermal generating plant is under construction at Pickering. The plant on completion in 1971, will discharge warm cooling water (10-25°F above lake temperature) at a rate of 1200 cfs. A study was conducted at the mouth of Duffin Creek to arrive at an estimate of the dispersion pattern. This stream which is tributary to Lake Ontario was selected because of its geographical proximity to the plant, the lack of a well formed delta, and the large marsh just upstream of the mouth which ponds and routes the flow. To simulate a thermal effluent, the study was conducted in the spring-time when the flow was 180 cfs and 5°F warmer than the lake water. Before conducting the study, a mathematical model was developed for the analysis of the dispersion data.

MATHEMATICAL MODEL

One form of the steady state one dimensional dispersion equation is:

$$\bar{U} \frac{dc}{dx} = E \frac{d^2c}{dx^2} \text{ — — — — — (1)}$$

where C = dye concentration ppm

$\bar{U}$ = mean velocity fps

x = distance ft.

The constant " E " called the diffusivity has been found to be a variable. Diffusivity (E) is a function of mean velocity gradients, turbulence and thermal stratification with the result that various techniques have been designed to define the variability of E . Some of the most successful methods in natural stream flows have utilized the measurement of mean velocities in two dimensions (Fischer, 1967). However, these methods are not easily adapted to dispersion in the lakes where velocities along the shore are $0.1 \rightarrow 0.3$ fps. Csanady in the Bale du Dore study (Csanady, 1964) found diffusivity to be highly variable in both dimensions in Lake Huron.

G. Gifford (1955, 1957, 1960) proposed a dispersion model for a continuous source based upon a 2-dimensional Gaussian distribution using measured values of the variances in two dimensions. This method uses a mass balance criteria. J.E. Foxworthy et al (1966) successfully applied Gifford's model to the dispersion study at Los Angeles, for a point source.

$$\bar{c}(x,y,z) = \frac{Q}{2\pi(\bar{\sigma}_y^2 \bar{\sigma}_z^2)^{1/2} \bar{U}} \exp - \left(\frac{y^2}{2\bar{\sigma}_y^2} + \frac{z^2}{2\bar{\sigma}_z^2} \right) \quad (2)$$

where Q = mass flow of dye in lbs/sec.

$\bar{\sigma}^2$ = average variances ft^2 .

y = depth measured from the surface in ft.

z = distance measured parallel to the water surface perpendicular to y ft.

$$\bar{C}_{\max}(x) = \frac{Q}{\pi (\bar{\sigma}_y^2 \bar{\sigma}_z^2)^{1/2} \bar{U}} \quad \text{--- (3)}$$

Equations (2) and (3) are for a point source and require modification for a steady state area source as follows (See Foxworthy (1966) for detailed development and assumptions):

$$\bar{C}(x, y, z) = \left(\frac{2Q}{\pi \bar{U} [2\bar{\sigma}_y^2(x) + \bar{\sigma}_y^2(0)]^{1/2} [2\bar{\sigma}_z^2(x) + \bar{\sigma}_z^2(0)]^{1/2}} \right) \exp \left[- \left[\frac{y^2}{2\bar{\sigma}_y^2(x) + \bar{\sigma}_y^2(0)} + \frac{z^2}{2\bar{\sigma}_z^2(x) + \bar{\sigma}_z^2(0)} \right] \right] \quad \text{--- (4)}$$

$$\bar{C}_{\max}(x) = \frac{2Q}{\pi \bar{U} \bar{\sigma}_y(0) \bar{\sigma}_z(0) \left[\frac{2\bar{\sigma}_y^2(x)}{\bar{\sigma}_y^2(0)} + 1 \right]^{1/2} \left[\frac{2\bar{\sigma}_z^2(x)}{\bar{\sigma}_z^2(0)} + 1 \right]^{1/2}} \quad \text{--- (5)}$$

$$\bar{C}_{\max}(0) = C_0 = \frac{2Q}{\pi \bar{U} \bar{\sigma}_y(0) \bar{\sigma}_z(0)} \quad \text{--- (6)}$$

$$\bar{C}_{\max}(x) = \frac{C_0}{\left[\frac{2\bar{\sigma}_y^2(x)}{\bar{\sigma}_y^2(0)} + 1 \right]^{1/2} \left[\frac{2\bar{\sigma}_z^2(x)}{\bar{\sigma}_z^2(0)} + 1 \right]^{1/2}} \quad \text{--- (7)}$$

The variances were determined on an individual point basis as suggested by Foxworthy

$$\sigma^2 = \frac{\sum f_i x_i^2 - \frac{(\sum f_i x_i)^2}{n}}{n-1} \quad \text{--- (8)}$$

A short bibliography on lake currents is included to assist in the selection "U" values for computations without drogue studies for estimating purposes.

EXPERIMENT

Rhodamine B dye was injected (see Fig. 1) at a rate of approximately 200 ppb (a flow gauge existed two miles upstream of outlet). The distribution of the dye was not uniform at the outlet due to the non-uniform mean velocity (see Fig. 4). The surface layer and the eastern side of the creek were actually flowing upstream due to the wind conditions. Consequently, the mass flow term "Q" was determined by integrating the concentration and velocity profiles at the outlet. The longshore currents were measured by tracking drogues at a two foot depth placed 500 feet directly south of the outlet while wind velocities were measured with an anemometer, (Table 1). Once the direction of the current was determined, marker buoys were established at the various range lines (constant distances from creek outlet) using an optical range finder. Dye was continuously injected at a steady rate. Once the plume had reached approximately 6000 feet from the source, sampling was started on the

nearest range line. The boat traversed the dye plume sampling at a depth of two feet to determine the location of the maximum concentration in the "Z" direction. At this point, samples were taken at one foot intervals (y-direction) to determine the depth to the maximum concentration. The vessel then made a complete traverse from well off-shore to the shore, sampling at the depth of maximum concentration. Positions were determined from the shore using a transit mounted optical range finder with a one meter base. All concentrations were measured with a fluorometer.

Dye was normally injected for about three hours with the result that the wind conditions varied little (see Table 1). Two runs were made under different wind conditions resulting in a Western and Eastern dispersion pattern, but in each case, the temperature of the creek water was 44°F. and the lake temperature 500 feet offshore was 39°F.

RESULTS

In both studies, the maximum concentration of dye remained very near to the shoreline at each range line. Sampling was restricted to depths of approximately 1.5 feet due to the draft of the small boat. It was observed that the dye plumes were wider dispersed at 500 feet than at 1000 feet. This is probably due to the inertia of the creek flow which is directly south with a mean velocity of 0.5 fps. The inertia of the creek water must be dissipated, then redirected along the shore to conform with the wind driven lake currents along the shore. Beyond

this initial spreading at the mouth, the concentrations on the average varied as $x^{-0.7}$ in the westerly direction and as $x^{-0.78}$ in the easterly direction. Csanady (1967) found the concentration varied approximately between $x^{-1.0}$ and $x^{-0.7}$. The confinement of the thermal regime produced higher concentrations in a narrower zone along the shore.

The dye concentration profiles at the various distances from the mouth are presented in Figs. 2,3,4,5 and 6 and the variances ($\bar{\sigma}^2$) for each profile appear in Fig. 7. The distribution of dye with depth is fairly uniform and appears to have a constant variance of approximately one foot (Fig. 6). This is probably due to the bottom having a uniform away-from-shore gradient.

To apply the prediction model, it was necessary to develop a relationship between the variance and distance from the outlet. Foxworthy fitted a straight line to a plot of $\log \sigma$ vs $\log x$. However, this method produces erroneous results when applied to Duffin Creek due to the initially large plume at 500 feet from the creek mouth. A two segment line was fitted to the measured variances by joining the variance at the creek outlet and the variance at 1000 feet, then a second line was fitted for distances greater than 1000 feet. This method produced a good prediction model for maximum concentration for Duffin Creek, but failed to define the initial large spreading of the plume at the creek outlet which would probably be dependant on the creek flow and cross section. This study also failed to define the relationships between variances and different

thermal lakewise temperature gradients, which are likely a factor as Csanady's concentrations vary approximately as x^{-1} to $x^{-0.7}$ in the summer and the Duffin Creek study vary approximately as $x^{-0.8}$. Further, the study failed to define the relationship between variances and longshore currents.

MODEL COMPUTATIONS - WESTERN PLUME

The model maximum concentrations were computed by substituting the following values into equations 5 and 6:

X feet	Q lbs/sec	$\bar{U}$ fps	$\bar{\sigma}_y$ ft	$\bar{\sigma}_z$ ft
0	11.1×10^{-4}	0.58	3.16	5.36
500	11.1×10^{-4}	0.43	0.94	36
1000	11.1×10^{-4}	0.33	0.97	42
2000	11.1×10^{-4}	0.33	0.97	67
4000	11.1×10^{-4}	0.33	0.97	108

The variation in velocity downstream was accounted for by employing dimensionless velocity ratios to equation 5. The results are as follows:

Distance ft	C _{max} Measured ppb	C _{max} Model ppb	Percent Difference %
<u>WESTERN PLUME</u>			
500	130*	150	18
1000	205	170	17
2000	130	112	14
4000	72	70	3
<u>EASTERN PLUME</u>			
500	140	175	25
1000	100	94	6
1500	60	70	13

* True maximum missed.

A temperature and drogue study conducted at an existing thermal generating station, (Lakeview) with a cooling water flow of 1160 cfs at a temperature of 62.6°F. in May showed that the warmer water stays near the surface and the shore (see Fig. 9). The sub-surface cooling water had acquired lake temperature by 4000 feet while the surface cooling water is still 4°F. warmer than the lake water at 4000 feet. The Duffin Creek dye plumes were similar in configuration to the measured Lakeview thermal plumes.

The Duffin Creek model was applied to the Lakeview thermal plant site to predict maximum downstream temperatures, based on temperature and flow data at the outlet (assuming constant along shore currents and heat as a complete conservative with no atmospheric heat transfer) the following results were obtained:

Distance from the Outlet feet	Predicted Maximum Temperature °F	Measured Maxi- mum Temperature °F	Difference %
500	60.5	62.6	7
1000	57.0	62.6	18
2000	53.4	60.8	25
4000	50.7	53.4	12

It must be appreciated that the transposed model is an estimate which can only be applied to along shore plumes. A more comprehensive model would take into consideration current regimes, thermal stratification and atmospheric transfer and probably wave considerations.

CONCLUSIONS

A mass flow model based on measured concentration profiles for continuous constant dye injection was developed for a creek with a flow of 180 cfs into Lake Ontario in the presence of a thermal difference of 5°F. between the creek and the lake. The model predicts

dye concentrations within 25 percent of measured values in the effluent plume for a mile from the outlet and vary as the $(\text{distance})^{-0.8}$. The developed model was then used to predict the maximum temperatures in the effluent plume of an existing thermal generating station and was capable of predicting maximum temperatures within 25 percent of the measured values.

TABLE 1

WIND CONDITIONS

DUFFIN CREEK - APRIL 10/68

Time	Force (Knots)	Direction	Activity
WESTERN			
0900	4	245 ^o	
1000	7	280 ^o	dye injection
1115	10	285 ^o	
1330	10	280 ^o	sampling
1500	11	280 ^o	
1540	7	280 ^o	
EASTERN			
0700	5	110 ^o	
0815	5	110 ^o	
0930	4	95 ^o	
1110	3	95 ^o	
1150	8	113 ^o	
1330	15	60 ^o	
1430	11	50 ^o	dye injection
1700	1	50 ^o	
1815	0	0 ^o	sampling

APPENDIX

LIST OF SYMBOLS

x	-	distance measured in the direction of the dye plume movement - feet
y	-	depth measured from the surface - feet
z	-	distance measured parallel to the water surface and perpendicular to x - feet
$\bar{U}$	-	mean velocity in x direction fps
$\bar{\sigma}^2$	-	variances in y and z direction ft^2
Q	-	mass flow rate of dye lbs/sec
f _i	-	frequency
c	-	concentration ppm

REFERENCES

- Csanady, G.T. 1964 Hydrodynamic Studies on Lake Huron at Baie du Dore, Summer 1964. Water Resources Institute, University of Waterloo and Great Lakes Institute, University of Toronto. PR 19
- 1967 Douglas Point Saturation Run, 1967. University of Waterloo, Great Lakes Institute. PR 30.
- Fischer, Hugo B. 1967 Analytical Prediction of Longitudinal Dispersion Coefficients of Natural Streams. 12th Congress Intl. Assoc. for the Hydralic Research V4, P. 11.
- Foxworthy, J.E., Tibby R.B. and Barsom, G.M. 1966 Dispersion of a Surface Waste Field on the Sea. Journal Water Pollution Control Federation. V.38, No. 7. P. 1170.
- Gifford, Frank Jr. 1955 Atmospheric Diffusion from Volume Sources. Journal Meteorology V. 14. (5), P. 410
- 1957 Relative Atmospheric Diffusion of Smoke Puffs Journal Meteorology V. 14(5), P. 410
- 1960 Peak to Average Concentration According to a Fluctuation Dispersion Model. Int. Journal Air Pollution. V.3 No. 4, P. 253, Pergamon Press 1960.

LONGSHORE CURRENTS - BIBLIOGRAPHY

Le Mehaute B. and Breoner A. An Introduction to Coastal Morphology and Littoral Processes. Queens University, Civil Engineering Depart. No. 14. 1962

Inman, D.L. and Quinn, W.H. Currents in the Surf Zone. Coastal Engineering in Japan. P. 195.

Dutnam, Munk and Taylor. The Prediction of Longshore Currents. Trans American Geoph. Union. V. 30 P. 337-45, 1949

Shepard and Inman. Nearshore Circulation Related to Bottom Topography and Wave Action. Trans American Geoph. Union, V.31 1950

Hamblin P.F. and Rodgers G.K. The Currents in the Toronto Region of Lake Ontario. Great Lakes Institute, Union of Toronto P.R. 29 1967

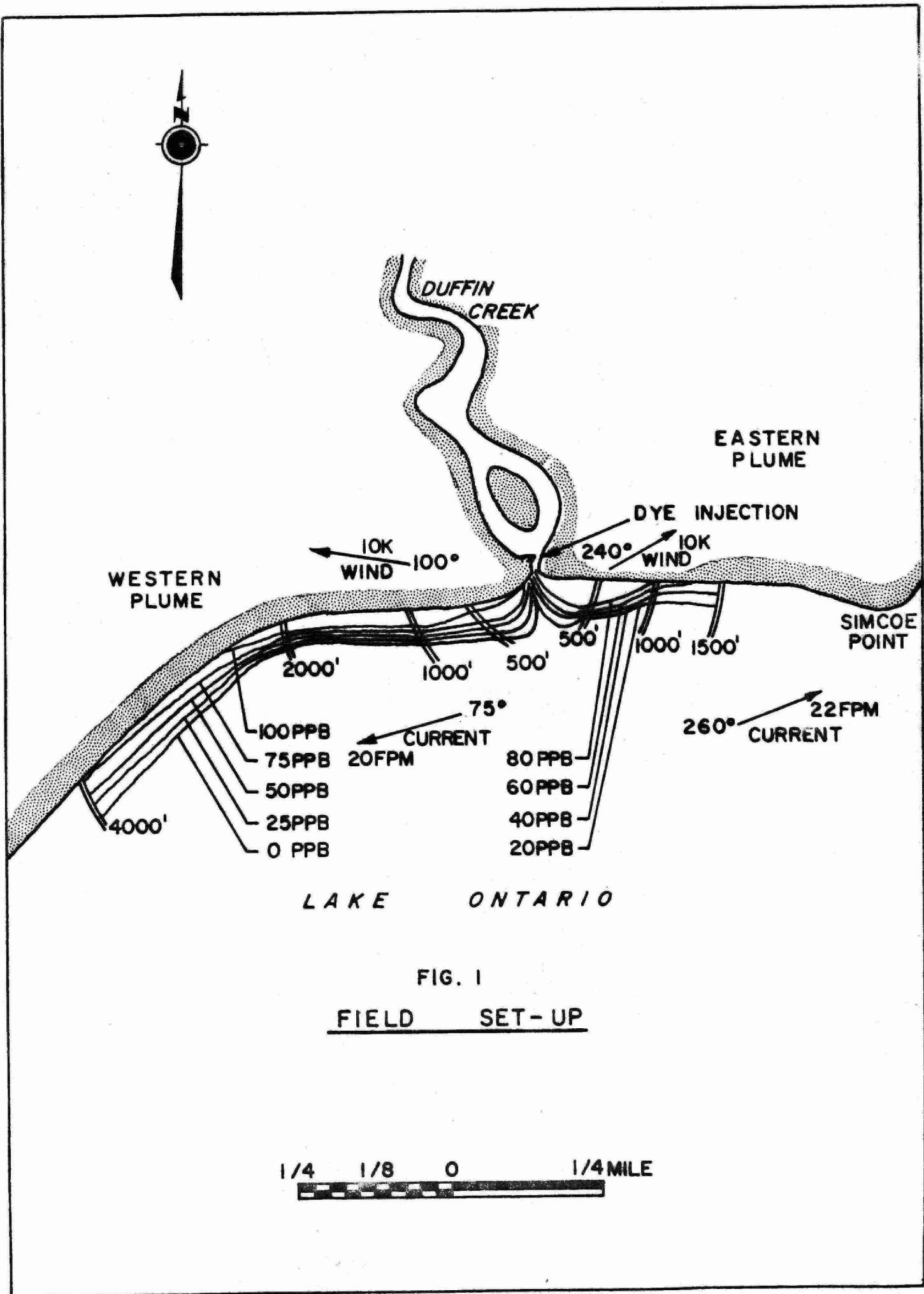


FIG. 1
FIELD SET-UP

FIG. 2
WESTERN PLUME

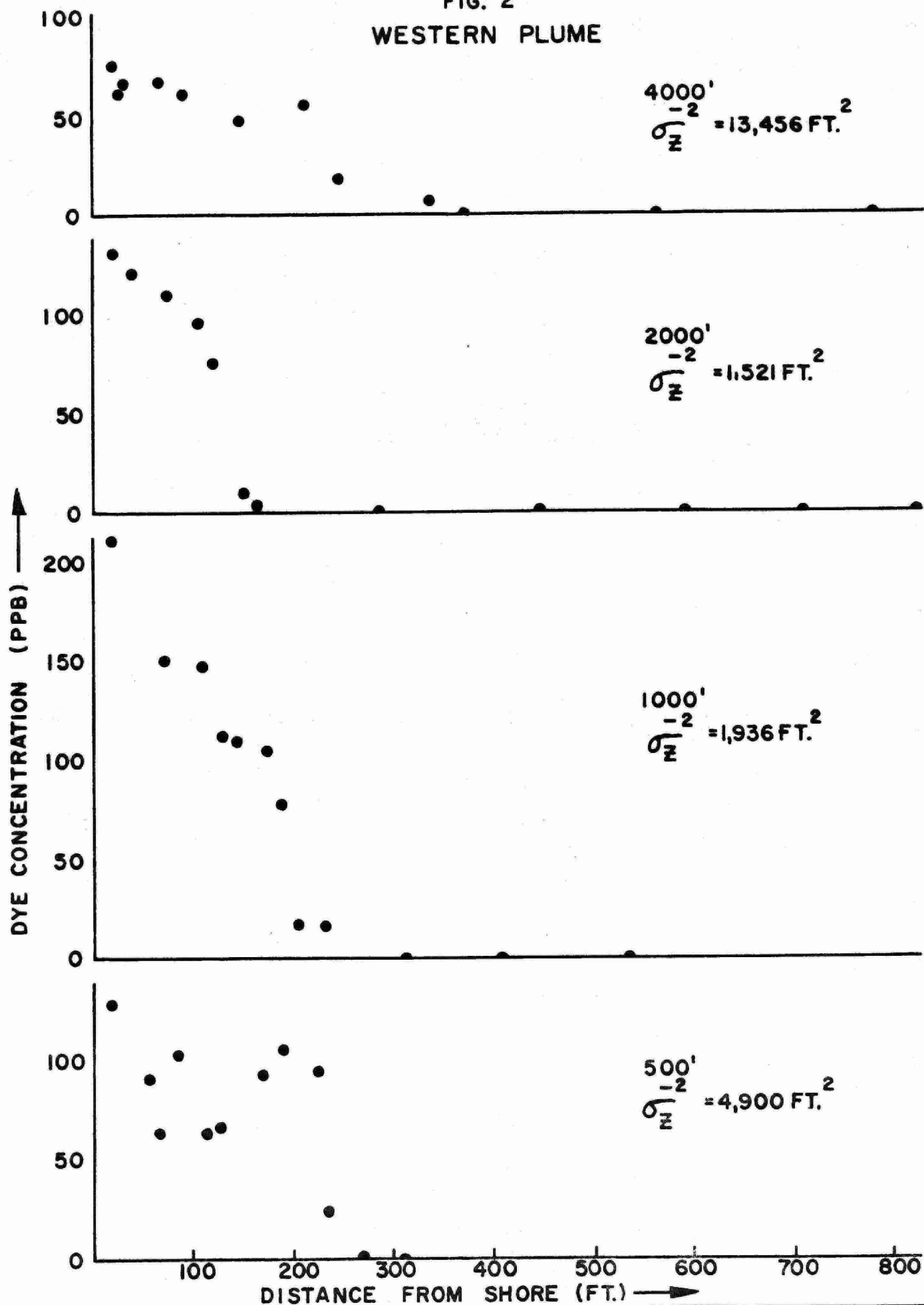


FIG. 3

EASTERN PLUME

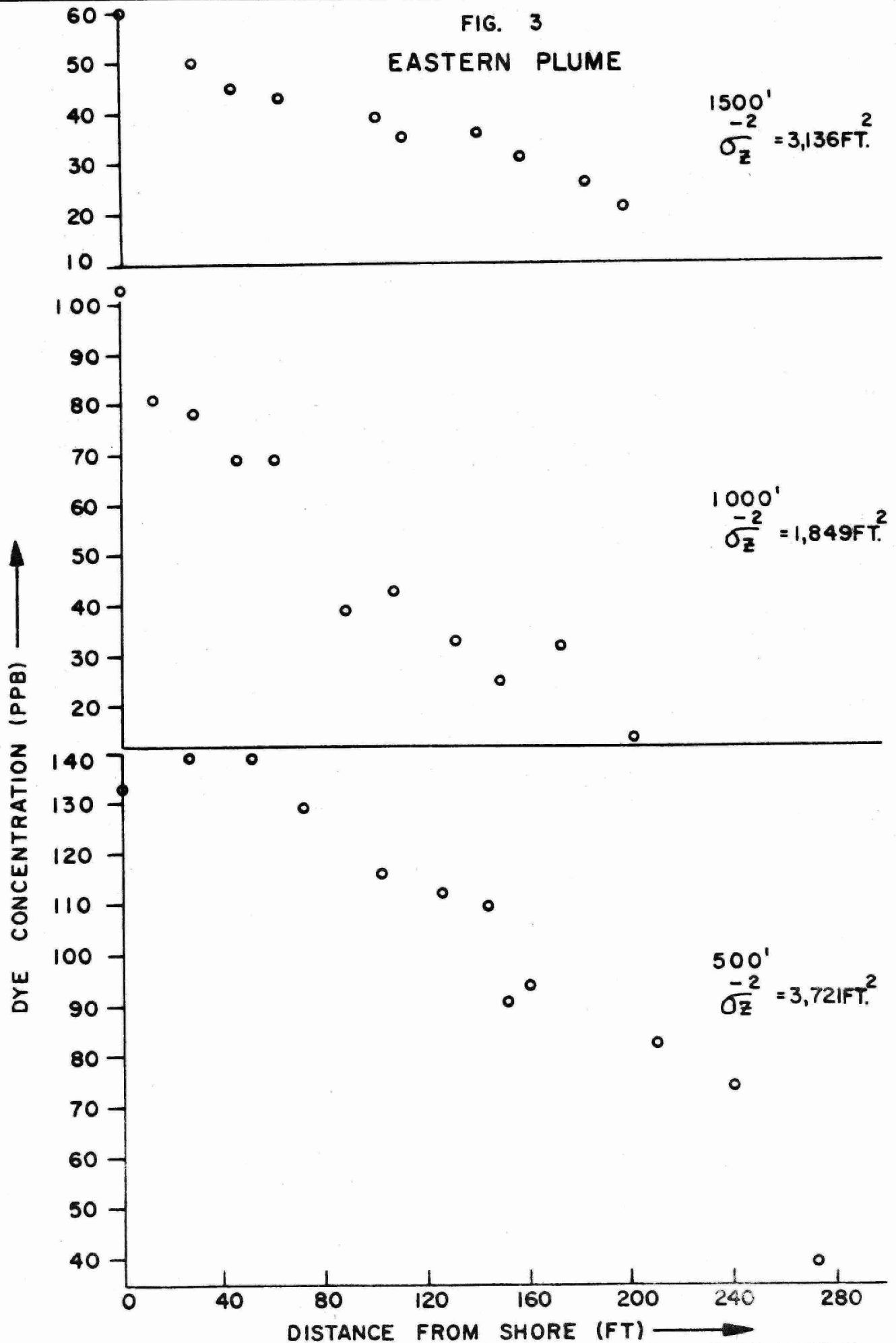


FIG. 4
 DUFFIN CREEK OUTLET CROSS SECTION
 VELOCITY AND CONCENTRATION
 VALUES
 (WESTERN STUDY)

LEGEND

-.26 VELOCITY (FEET PER SECOND)
 ○ DYE CONCENTRATION (PPB)

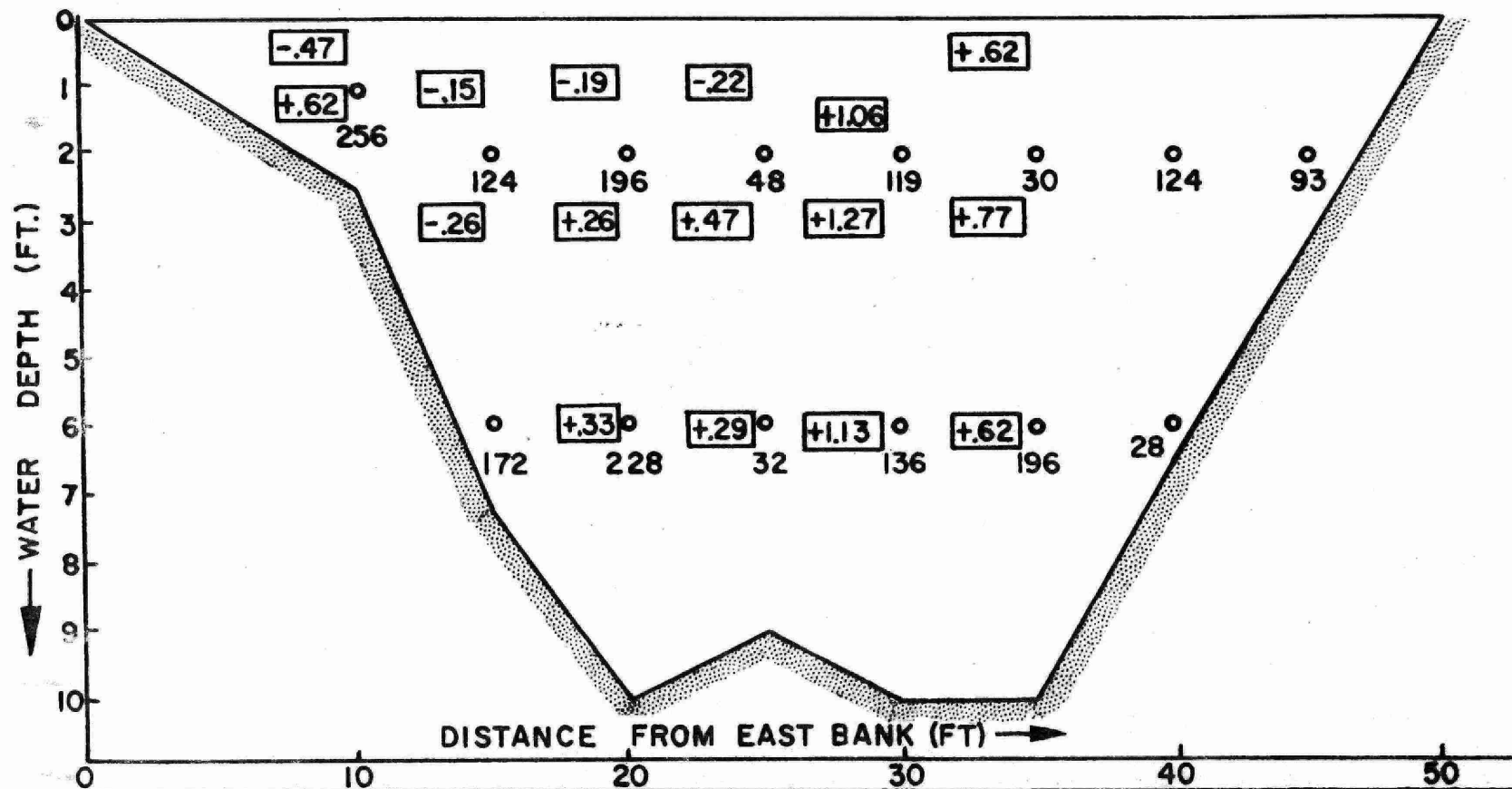


FIG. 5

DYE CONCENTRATIONS VS. DISTANCE

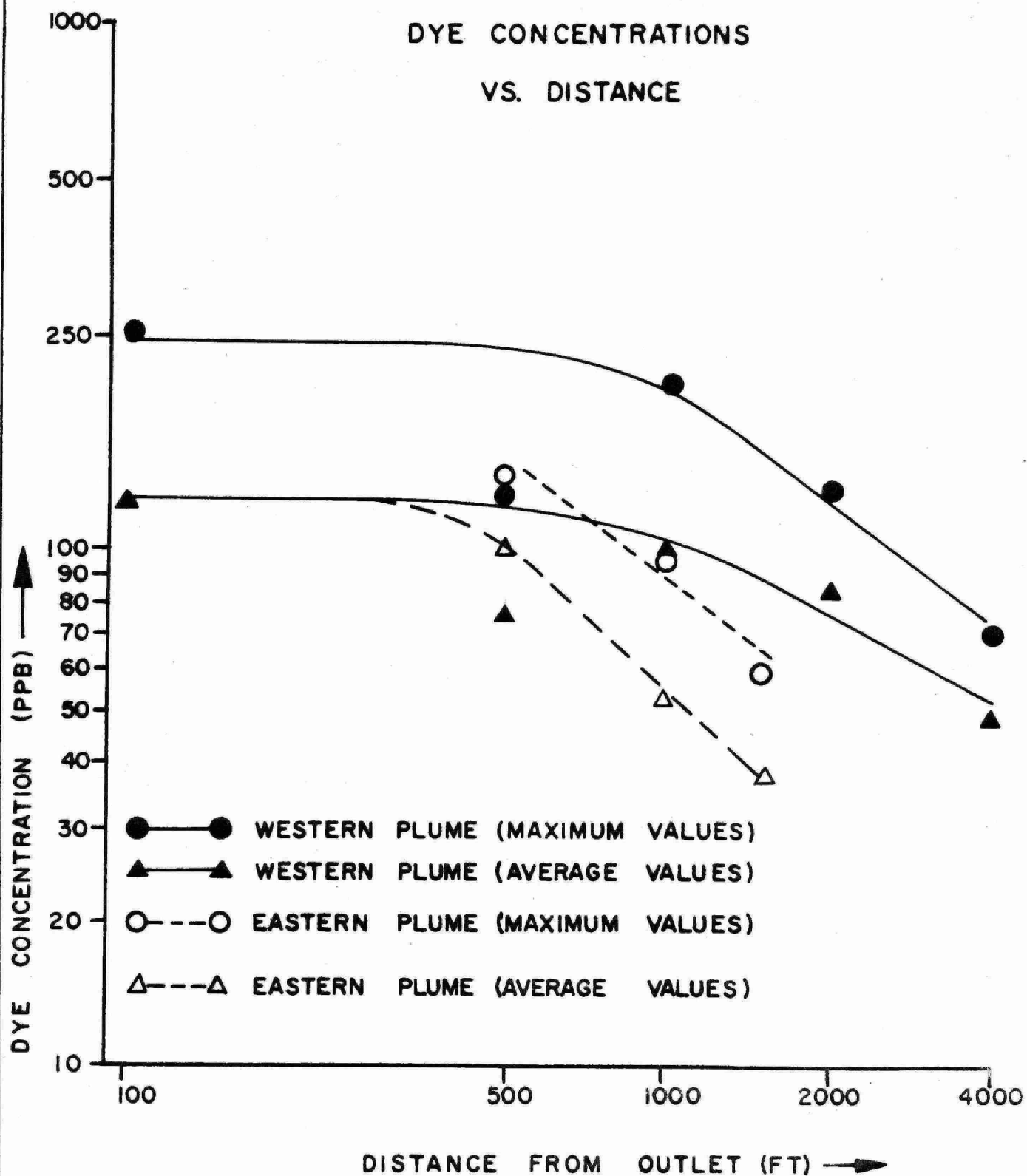


FIG. 6

VERTICAL DYE CONCENTRATIONS
WESTERN PLUME

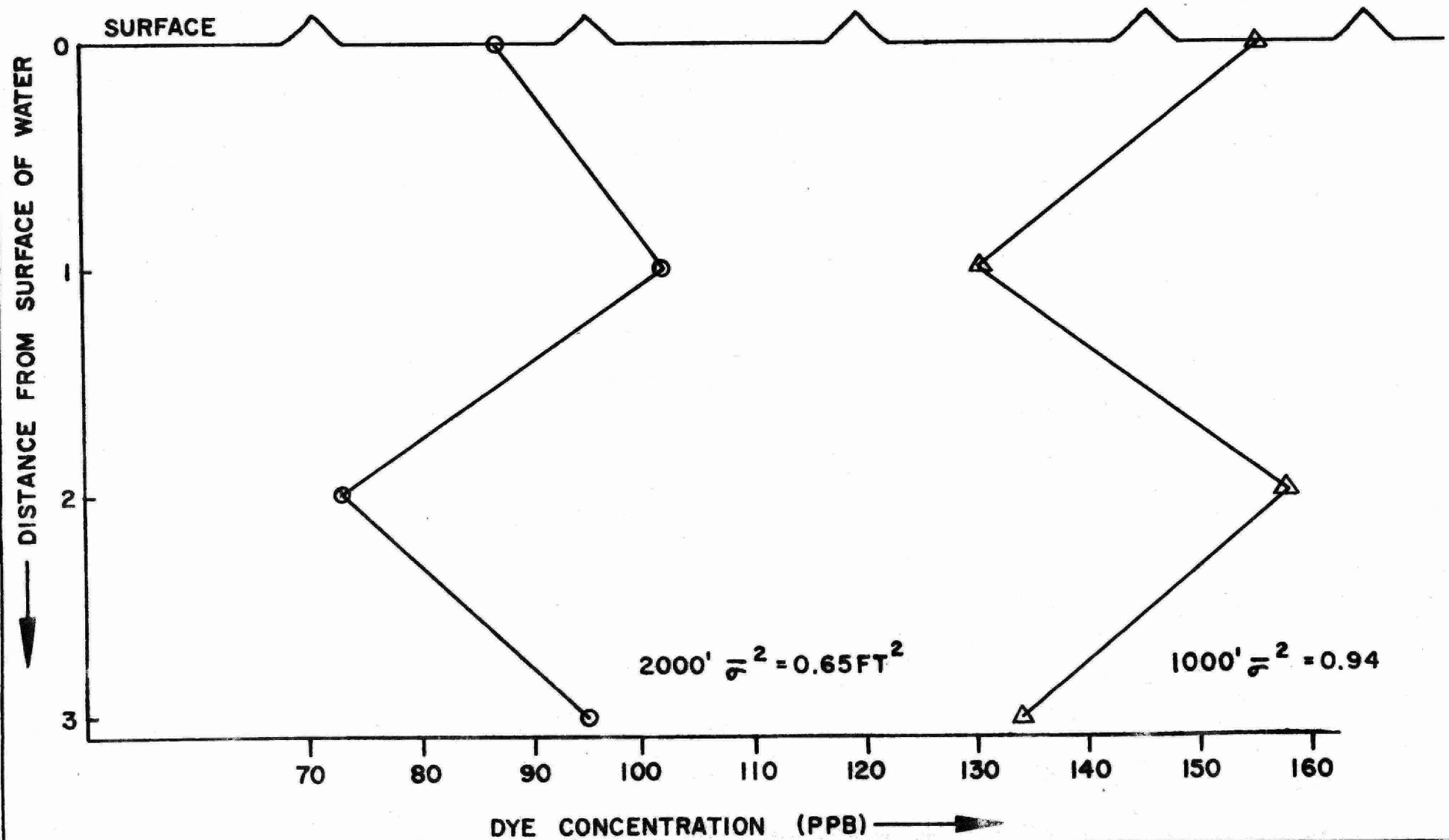


FIG. 7
VARIANCE σ_z^2 VS. DISTANCE

LEGEND

- WESTERN PLUME
- EASTERN PLUME

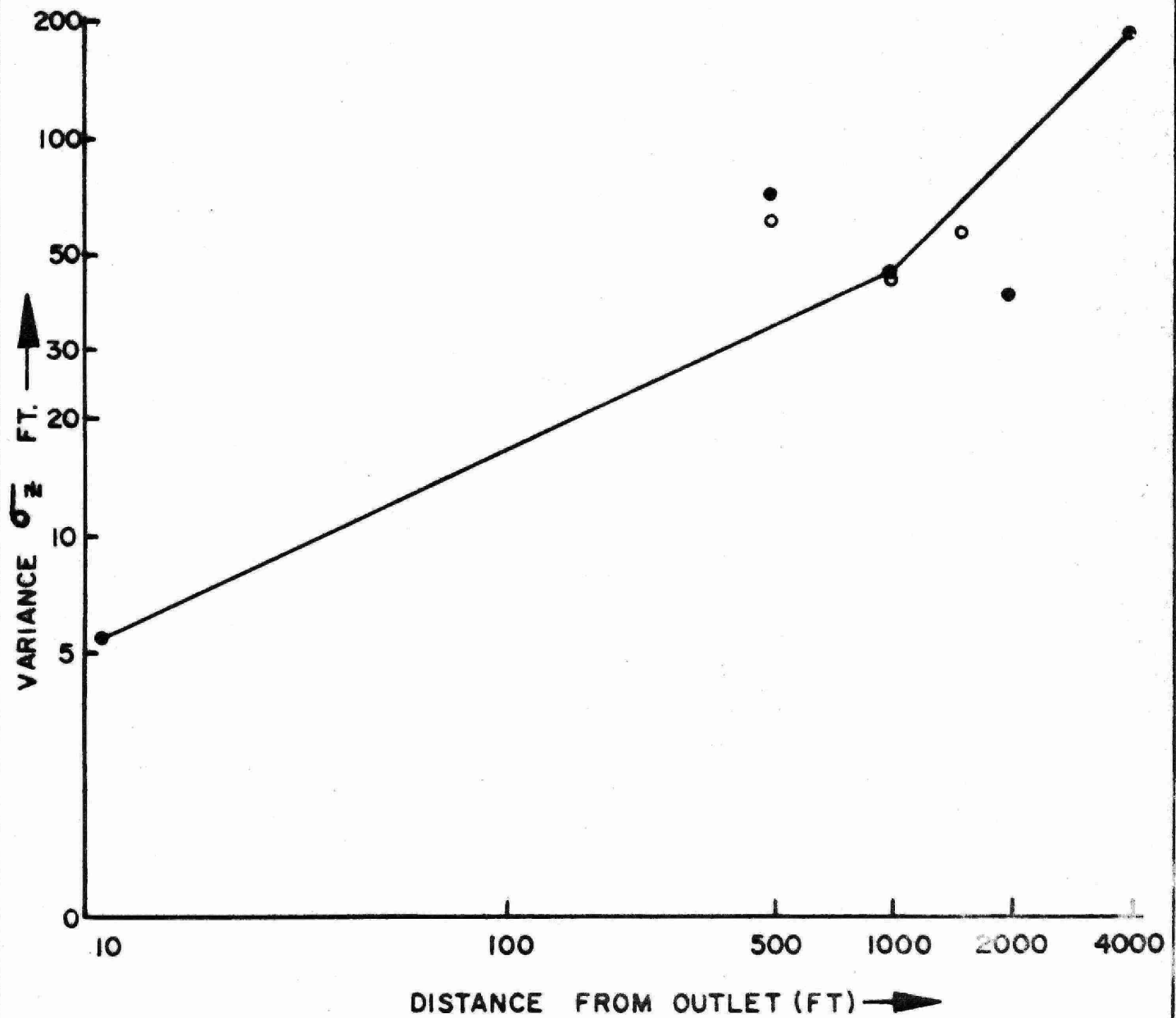
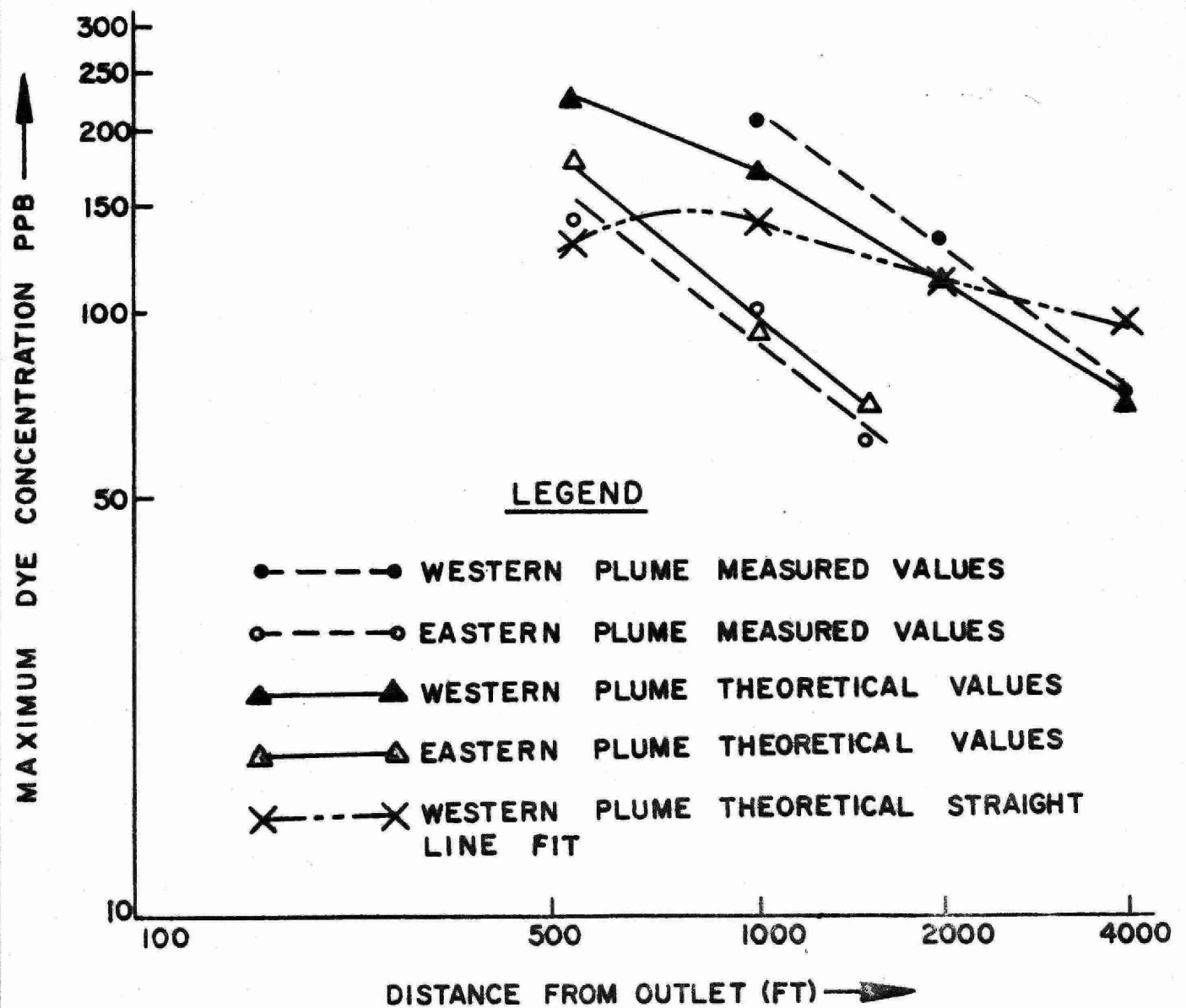
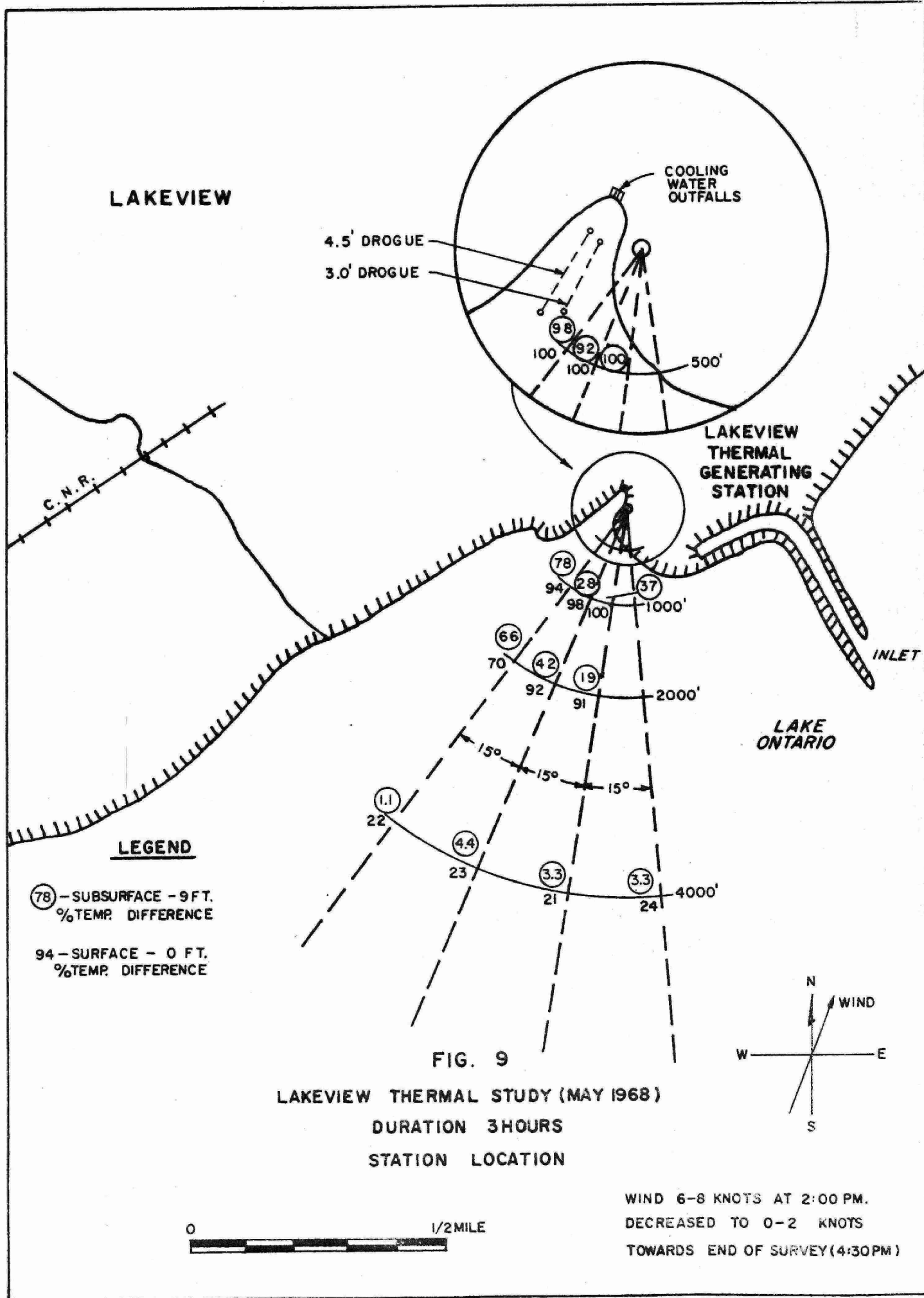


FIG. 8
MODEL AND EXPERIMENTAL
RESULTS







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